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THE CRANIAL NERVES. A REVIEW OF FIFTY YEARS

C. JUDSON HERRICK[1]

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I

Current activity suggests that we are now at the threshold of important, perhaps revolutionary, changes in outlook and method in the investigation of the major problems of neurology. The clear formulation of the doctrine of the reflex about a hundred years ago inaugurated a century of intensive research which culminated in systems of reflexology which endeavored to explain all nervous functions in terms of mechanical models designed upon principles similar to those of an automatic telephone exchange. These studies yielded much of theoretical and practical importance, but failed to supply the key to unlock the mysteries that still baffle every attempt to understand the actual operation of our nervous systems.

The analytic functions, typified by reflex, have been thoroughly explored, but we are still in the dark about how these partial patterns of behavior, as defined by the late G. E. Coghill, are synthesized in a total pattern as we see it in operation in solving problems of conduct. And however completely this stimulus-response type of activity may be understood, there remain also those centrally initiated processes which exhibit an apparent spontaneity whose pattern of manifestation is quite unpredictable in terms of any stimulus-response mechanism yet conceived.

We now know that in the early development of the nervous system structural differentiation is initiated and carried through to functional capacity by intrinsic agencies of growth before any sensory influence can act upon it. The motor systems mature earlier than the sensory systems, and even in the adult the neuromotor apparatus is so organized that it is capable of executing perfectly coordinated movements independently of any sensory excitation—and it actually does so under some conditions. Indeed Coghill went so far as to write in one of his unpublished papers, "It is generally assumed that sensory functions are primary to motor functions, antedate them in development, or underly them in function. But this cannot be accepted as universally true; probably it is never true. The primary significance of the sensory functions is orientation of action, not its excitation."

The so-called spontaneous activities are centrally controlled, and every typical reflex or other stereotyped pattern of response to simulation may be modified by intercurrent influences from central adjustors. The significance of reflex in the vital economy cannot be understood apart from the total pattern of nervous adjustment within which it is set. This is graphically illustrated by the fact

[1] Aided by a grant from the Dr. Wallace C. and Clara A. Abbott Memorial Fund of The University of Chicago.

that when Sir Charles Sherrington, to whom we owe our most comprehensive and critical knowledge of reflexes, summarized his studies in 1906 he entitled his book, "The Integrative Action of the Nervous System."

The major neurological problems of today and tomorrow converge upon the apparatus of integration and how it operates, upon the central control of all nervous functions. Since the turn of the century revolutionary improvements have been made in our methods of study—new technical aids in anatomy, physiology and psychology—and upon these we base our hopes for ultimate solution of these recondite problems.

The invention of the oscillograph and related instruments for recording the electrical properties of nervous tissue in action has opened a vast field, the systematic exploration of which has only begun, with possibilities for the future that seem unlimited. Attention was first directed to the peripheral nerves and their end-organs, which are, of course, most accessible for experiment, and we now have much exact information about what is going on in nerve fibers of various sizes and structure during nervous conduction. Most of these peripheral nerve fibers connect with the central nervous system and the part that lies within the spinal cord or brain probably performs in much the same way as the peripheral part. But those physiologists who hope to explain the functions of the central adjustors in terms of the laws of conduction observed in peripheral fibers and nothing more are deluded. The central structure is radically different and no mechanical model has yet been devised which seems adequate to perform the functions observed in the behavior of men, monkeys or rats. All of these animals condition their reflexes, learn by experience, exhibit behavior which objectively we would call rational, can abstract from mixed experience its common features, and show types of spontaneity and initiative which conform with none of our standard categories of behavior. A rat, so far as we know, has no abstract ideas, say of a triangle, but he can and does distinguish a triangle from other geometric figures and recognize it, regardless of size, position or illumination. Operationally considered, this is an abstraction.

The patterns of these mysterious performances are determined in part by the inherited structure of the body—these are the reflex and instinctive components—and in part they are built up by the experience of the individual—the learned components. This experience comes to us through the sense organs and the related nerves, and these are the parts of the nervous system about which our knowledge is most exact. Though the intricate operations of the brain cannot be explained in terms of the simple laws of conduction seen in peripheral nerves, yet our knowledge of the realities of the outside world, to which we must adjust, all comes to us through the peripheral neurosensory systems: whatever course of conduct may be adopted in the light of this knowledge must be effected through the agency of the peripheral neuromuscular organs. It is obvious that there can be no understanding of the operations of the brain without accurate knowledge of the nerves which connect this central adjustor with the peripheral apparatus through which we have our only contacts with environment. It may well be that we shall find, after all, that the peripheral nerves contain the threads of Ariadne which will guide our steps through the labyrinths of the brain.

But even here we are confronted with apparently unsurmountable difficulties when we attempt to construct any kind of a working model in terms of classical mechanical principles. A survey of the activities in this field during the fifty years just passed will point to notable advances and bring out in sharp relief the problems yet to be solved. It was my good fortune to participate in some of these episodes and some comments upon them may now be opportune.

II

During the 1880's the late Henry Fairfield Osborn, then at Princeton, was interested in the comparative anatomy of living and extinct vertebrates and he early recognized that the lower amphibians—salamanders and their allies—occupy a strategic position in the evolutionary series. Their brains, like their skeletons, are generalized and show instructive intermediate stages between those of fishes and terrestrial animals. Comparison of these brains with those of fishes, some of which are highly specialized for aquatic life, and with those of higher animals revealed many problems and few solutions, for the forms of these brains are so diverse that the homologies of even their major subdivisions were in controversy.

All of these lower brains lack the cerebral cortex, and those other centers of more complex adjustment which compose the larger part of the human brain-stem are in very rudimentary condition. Most parts of these brains are in direct connection with the periphery through the cranial nerves, and their primary functions evidently are immediate responses of reflex type to events occurring outside or inside the body. Obviously the key to the analysis of their structure lies in these nerves and the specific functions which they serve.

During the nineteenth century the cranial nerves of many fishes and other lower vertebrates were minutely described. These early anatomists were masters of dissection, but their skillful use of the scalpel could take them only as far as the surface of the brain. The brains, it is true, had been examined microscopically, but no one had bridged the gap between the microscopic structure of the brain and the peripheral distribution of the nerves. The nerves are mixtures of sensory and motor fibers whose peripheral connections were known, but there was little known about the central connections of these several components. Subsequent research has shown that the guesses made were often widely at variance with the facts, and the resulting confusion was distressing. It is probably difficult for the younger men of the present day to realize the hopeless confusion and unintelligibility of the literature of the cranial nerves of this period.

The human cranial nerves were arbitrarily numbered from 1 to 12 and the voluminous literature about these nerves in lower vertebrates was an incohate mass, accurate in detail but almost meaningless. This I know because I was obliged to read most of it in course of preparation of a doctor's dissertation. Confronted with this situation, Professor Osborn, about 1890, conceived the idea that it might be possible to resolve the chaos by cutting serial sections through the entire body of a small animal and then analyzing each nerve trunk

under the microscope into its components. If each component were traced peripherally to its end-organs and centrally to its proper station within the brain, then the brain itself would be analyzed into regions defined by their peripheral connections, sensory or motor as the case might be. Thus a physiological analysis would be effected by an anatomical method and morphology would begin to make sense in terms, not of abstract principles, but of actual use in the operations of adjustment.

This research was undertaken by one of Professor Osborn's students at Princeton and later at Columbia, Oliver S. Strong, and it was brought to successful conclusion in his dissertation published in 1895.[2] In this period, while still an undergraduate at the University of Cincinnati and later at Denison, I was fumbling with the same problem. Upon the appearance of Dr. Strong's thesis it was evident that his method was practicable and fruitful and I resolved to work with him. During the academic year of 1896–7 I sat vis-a-vis with Strong at a table in the Columbia zoological laboratory.

Strong selected for study the tadpole of the frog, an animal of convenient size and generalized structure. Here the plan of organization of the vertebrate peripheral nervous system is shown in diagrammatic simplicity. I chose to work upon one of the bony fishes, the marine "silver-sides," Menidia, because we wanted to see what form this plan would take in a highly specialized species. The results were published in 1899.[3]

These studies clearly showed that the significant units of structure here are not the twelve pairs of nerves as arbitrarily numbered or any primitive segmental arrangement from which these nerves may have been derived phylogenetically. The components of the cranial nerves fall into classes which are functionally defined. All fibers of each class, regardless of variations in the peripheral distribution of their end-organs and regardless of the particular nerve trunks and roots through which they connect with the central nervous system, are segregated within the brain, where they converge into local areas or zones. These primary sensory and motor fields may be enlarged through secondary connections. In fact, most of the substance of these lower brains may be subdivided in terms of their peripheral connections. Thus we have nose-brain, eye-brain, and so on.

Each of these structural units is also a functional unit, that is, a functional system comprising all nerve fibers and related end-organs and central connections which are so arranged as to respond to excitation in a common mode, either sensory or motor. Thus nerves from the skin comprise a general cutaneous system and viscera are innervated by visceral sensory and motor systems.

The early attempts to map the limits of these functional systems anatomically were crude and imperfect. A beginning was made by Majendie and Charles Bell in the experimental separation of sensory and motor roots of the nerves. This was followed by Gaskell's four-root analysis in which the somatic sensory and motor systems were separated from the visceral.

[2] Oliver S. Strong. The cranial nerves of the Amphibia. *J. Morph.* *10*, 101–230 (1895).

[3] C. Judson Herrick. The cranial and first spinal nerves of Menidia. *J. Comp. Neur.* *9*, 153–455 (1899).

At the turn of the century this analysis had been carried further. In the spinal nerves four systems were recognized—general somatic sensory and motor and general visceral sensory and motor. In the nerves of the head there are added to these general systems the various special systems, and no pair of cranial nerve roots repeats exactly the composition of any other pair. In the head the general somatic sensory system (cutaneous and deep sensibility) is concentrated in the V pair of nerves, with variable representation in the VII, IX and X pairs. The general visceral sensory is represented in the VII, IX and X pairs and the general visceral motor in the III, VII, IX and X pairs. The various special sensory systems are segregated—olfactory (I), optic (II), vestibular and cochlear (VIII), gustatory (VII, IX and X), and in aquatic species the lateral line system of sense organs, whose fibers enter by several roots to converge into the same field as the vestibular roots, i.e., into an area acusticolateralis. The innervation of the striated musculature of the head presents difficult problems to which reference will be made shortly.

These functional systems as defined before the close of the last century represent a rather coarse grouping of nerve fibers and their peripheral and central stations such as could be effected with the then available histological technique. The method employed, though very laborious and exacting, was soon applied to representatives of other groups of vertebrates by Norris, Coghill, Johnston, Willard, Pankratz and many others, and these investigations continue until now with improved technique and adequate physiological control. The result is that the analysis begun by Strong and subsequently carried on by what came to be called in Europe the American school of comparative neurologists is now firmly established and embodied in current literature. A table of human nerve components classified according to this system was published in Wood's Reference Handbook of the Medical Sciences, article Cranial Nerves (2d. ed., 1901; 3d ed., 1914) and in my Introduction to Neurology (1st. ed., Philadelphia, 1915).

This analysis is still incomplete and rather crude, for all of the sensory systems here defined are mixtures comprising several related modalities of sense which have not as yet been separable with available technique. The general somatic sensory system, for instance, includes a variety of kinds of cutaneous and deep sensibility which have not been satisfactorily segregated and the gustatory fibers are so intimately mingled with the general visceral sensory fibers in the nerve roots and brain as to defy analysis with present methods.

The striated musculature of the head has given comparative anatomists a world of trouble. The extrinsic muscles of the eyeball and the tongue muscles are evidently comparable with the somatic muscles of the trunk and this is confirmed by their embryological and phylogenetic development. The nerves which supply them (III, IV, VI and XII pairs) thus belong to the somatic motor system and because their end-organs are so specialized these are sometimes called special somatic motor nerves. The other striated muscles of the head, supplied by the V, VII, IX, X and XI nerves, also form a special group the status of which is ambiguous. In structure these resemble the somatic muscles and like them they are under voluntary control. But they have developed, both embryologically and phylogenetically, from the musculature of the jaws, hyoid and gill arches, and these are visceral structures. Shall they be called visceral because of their origin or somatic because of their structure and functions? In the latter case some homologous muscles would have to be

called visceral in lower vertebrates and somatic in higher. No matter which alternative is chosen, they certainly must be classed by themselves as special. They are innervated from the visceral motor column of the medulla oblongata and all students of nerve components term them special visceral motor. This is now the consensus among American anatomists, but with some reservations.

This classification is convenient for description, but it must not be too rigidly conceived, for the development and evolution of animal bodies are not bound by our rules of formal logic. In fact, the subject has given rise to considerable controversy. In 1922, when I sent to the editor of the British *Journal of Anatomy* an exposition of the analysis of nerve components employed by the American school,[4] this editor already had on his desk a vigorous attack upon our position by Raymond A. Dart.[5] The two papers appeared in the Journal side by side.

A few examples of the puzzles here encountered may be cited. The muscles of the larynx are of visceral origin, but they combine visceral and somatic functions; indeed they probably are the most highly specialized voluntary muscles of the human body. The frankly visceral musculature of the esophagus at its upper end is striated and under voluntary control. The framework of jaws, hyoid and gills has long been known as the visceral skeleton, yet curiously enough the embryological source of the primordia of some of these cartilages is the neural crest.[6] The related muscles are derived, not from somites, but from branchial mesenchyme and in fishes are visceral in function, though striated. Some of them retain these functions in mammals—mastication, respiration, etc.—while others, like the mimetic musculature of man, are strictly somatic.

In view of these variable and confusing relations of the musculature of the head it is not surprising that our nomenclature reflects the confusion. No simple formula is adequate and any terminology is necessarily arbitrary. The members of the American school call all striated muscles derived from the mesenchyme of the head special visceral in conformity with their genetic relationships. Some other anatomists have called them special somatic muscles in accordance with their adult anatomical structure. I now repeat the opinion expressed in 1922: "This difference in nomenclature is a matter of small importance, for the muscles do occupy an ambiguous position. . . . The essential thing is the recognition of their *special* character, in contrast with both the general visceral and the typical somatic neuromuscular systems."

The sensory components of the cranial nerves present a similar contrast between general visceral and general somatic systems, like those seen in the spinal nerves, and on the other hand various additional systems related with the organs of special sense. Here again visceral and somatic functions may be served by the same complex of nerve fibers, notably in the olfactory and gustatory systems. In most animals taste buds are all inside the mouth and are strictly visceral in function; but many fishes have taste buds all over the outer skin and these are exteroceptors, somatic in function. The general visceral sensory and the gustatory fibers are mingled in peripheral branches of the VII, IX and X cranial nerves and centrally in the fasciculus solitarius. This mixed system was termed the communis system in the early papers on nerve components.

At the Chicago meeting of the American Association of Anatomists on Jan. 1, 1902, I read a paper (unpublished) entitled, "An illustration of the value of the functional system of neurons as a morphological unit in the nervous system," in which this type of functional

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[4] C. Judson Herrick. What are viscera? *J. Anat. 56*, 167–176 (1922).

[5] Raymond A. Dart. The misuse of the term "visceral." *J. Anat. 56*, 177–188, (1922).

[6] F. L. Landacre. The fate of the neural crest in the head of the urodeles. *J. Comp. Neur. 33*, 1–43 (1921).

L. S. Stone. Experiments on the development of the cranial ganglia and the lateral-line sense organs in Amblystoma punctatum. *J. Exper. Zool. 35*, 421–496 (1922).

L. S. Stone. Further experiments on the extirpation and transplantation of mesectoderm in Amblystoma punctatum. *J. Exper. Zool. 44*, 95–131 (1926).

analysis by the anatomical method of reconstruction from serial sections was illustrated by current studies on the comparative anatomy of the facial nerve, which may be summarized as follows.

In the lowest fishes the facialis is a branchial nerve but little modified from the branchiomeric type found in the other nerves of the gills. Just as the glossopharyngeus forks around the first gill cleft, so the facialis forks around the spiracle. Here we find a posttrematic ramus containing motor and communis fibers for the musclature of the hyoid segment and the mucous membrane lining the lower jaw; a pretrematic ramus of communis fibers for the pseudobranch, a vestige of the mandibular gill in the spiracle, with an extension to the lining of the mouth between the hyoid and manidular arches; and the ramus palatinus of communis fibers for the roof of the mouth. In the higher fishes the communis rami of the facialis remain substantially the same as in the sharks in general plan, but with extraordinarily diverse and extreme modifications of the details, including in some species numerous taste buds in the outer skin with somatic sensory functions.

Now omitting the intermediate forms and passing at once to the human facialis, we note that despite striking metamorphosis with exaggeration of some components and reduction of others the characteristic features of the selachian pattern are readily identified. Thus the human nerve possesses a motor root and a communis root, the latter known as the portio intermedia and related geniculate ganglion. Peripherally of this ganglion the nerve forks around the eustachean tube, which we know from independent evidence is the phylogenetic derivative of the selachian spiracle. The great superficial petrosal nerve agrees with the ramus palatinus of fishes in all respects, the pretrematic ramus has disappeared with the loss of the related vestigeal gill, and the chorda tympani survives as a derivative of the posttrematic ramus, which probably distributes other fibers with the main facial trunk. The sensory facialis fibers are derived from the geniculate ganglion. These include general visceral sensory fibers for the mucous lining of the mouth, special visceral sensory fibers for taste buds, a small number of general cutaneous fibers to the auricular nerve, and perhaps some other functional types. The motor root and main facial trunk are composed chiefly of special visceral motor fibers, some of which retain visceral functions, though most of them supply the mimetic musculature which was derived phylogenetically from the branchial musculature but is now somatic in function. There is also a large general visceral motor component of preganglionic sympathetic fibers.

Since this paper was read further investigation by numerous workers has revealed amazingly diverse distribution of these components throughout the vertebrate series, yet, as was emphasized by the late Dr. Sheldon,[7] all of these aberrations have evidently been derived from a simple pattern which was established in primitive vertebrates and can be recognized in all descendants of these ancestral forms.

Looking back now over these fifty years of activity, it is a satisfaction to see that the labors of the pioneer period of analysis of nerve components succeeded in laying a secure foundation for the later studies. Now with improved histological and experimental methods the crudities and errors of the early accounts can be corrected and gaps in knowledge, formerly bridged by tenuous hypotheses, are now securely filled by well controlled observation.

III

When this analysis of the peripheral nerves was carried into the brain it immediately clarified the confusion and revealed a basic plan of structure of the lower brain-stem which is common to all vertebrates, though with wide variation in

[7] R. E. Sheldon The phylogeny of the facial nerve and the chorda tympani. *Anat. Rec.* *3*, 593–617 (1909).

details. In the medulla oblongata of primitive vertebrates the central stations of these systems are simply arranged as a series of longitudinal columns or zones, with the motor systems below and the sensory above. In the sensory field the general somatic and visceral-gustatory are below and the special somatic systems are added to these above and superficially. This arrangement is somewhat disturbed by secondary shiftings in the adult human brain, but in the embryo it is clear. Even in primitive brains this zonal pattern is not evident in the upper levels of the cerebrum, for here special systems and centers of adjustment of higher order dominate the picture. Human neurologists, accordingly, were slow to recognize the value of the comparative and embryological evidence as a guide to the interpretation of a complicated and confusing structure. Even the veteran comparative neurologist of Europe, Ludwig Edinger wrote me about 1908 that he recognized its merit, but added, "I fear I am too old a dog to learn the new tricks." But Edinger was not too old to change, and in the seventh edition of his "Vorlesungen," published in that same year, our analysis and our terminology were adopted (though with some unfortunate errors in labelling the figures).

The recognition of these primary centers of sensory and motor innervation seemed at first to conform exactly with the current conceptions of reflexology. There was apparently a clearly delimited central station for each modality of sense and for each category of muscular and glandular response, and it was my confident expectation that further study of the internal structure of these simplified primitive brains would reveal a pattern of reflex arcs showing well defined pathways of transmission from every type of sense organ to the appropriate organs of movement or secretion. This pattern, it was my hope, would provide the structural framework of the central nervous system, around which the details of the architecture of the higher centers of adjustment are arranged.

This hope was quickly and rudely extinguished, for when in 1914[8] I made a survey of the internal structure of the medulla oblongata of larval Amblystoma no well delimited central connections between the sensory zones and the motor zones were found. The arrangement of the peripheral neurosensory and neuromotor apparatus is somewhat like that of the outside connections of a telephone system, but the central switchboard seems to be lacking. An analysis of the components of the peripheral nerves of this salamander had been made by Coghill[9] and I found that each system of sensory fibers terminates in a definitely localized longitudinal zone of the medulla oblongata. But each entering nerve fiber divides into ascending and descending branches which span the entire length of the medulla oblongata, giving off collateral branches everywhere along its course. No fore-and-aft localization of function is provided by such an arrangement.

Moreover, at the first synaptic junction the nerve cells of the second order

[8] C. Judson Herrick. The medulla oblongata of larval Amblystoma. *J. Comp. Neur.* *24*, 343–427 (1914).

[9] G. E. Coghill. The cranial nerves of Amblystoma tigrinum. *J. Comp. Neur.* *12*, 205–289 (1902).

which are activated by these primary peripheral nerve fibers are not segregated in relation to the several sensory systems of incoming fibers. One of these secondary neurons may send dendrites out to engage terminals of sensory fibers from the skin, from taste buds and from the internal ear. It is anatomically possible for one of these cells to be activated simultaneously from all of these sense organs. If the skin of the face is pricked, the head is turned away—a typical reflex. If food in the mouth stimulates taste buds, it will be swallowed. But there is no specific and insulated connection within the brain between the the terminals of cutaneous nerves and the motor nerves for the neck muscles or between gustatory terminals and the neuromotor apparatus of swallowing. A single central neuron may be activated by either of these sense organs, and how the choice is made between the two ways of responding to a stimulus remains obscure. The physiological specificity of the peripheral nerve fibers seems to be partially or wholly lost in the neurons of the second order, for the nervous elements of the central nervous system are not segregated into local nuclei and tracts, each of which is connected with only one of the peripheral sensory systems. Every central neuron is a correlating element, but how is the correlation effected?

The axons of the secondary neurons may extend for long distances, ascending or descending or in both directions, and throughout this course they may give off innumerable collateral branches to all contiguous parts. The entire substance of the brain is permeated by a dense feltwork of such fine branching fibers, the neuropil, and when a nervous impulse passes along any one of the major nervous pathways there may be a seepage of excitation which spreads diffusely, exerting a non-specific influence of wide extent.

In brief, the texture of the tissue of the primitive central nervous system is such as to make no provision for any kind of known adjusting mechanism of switchboard type. Most of the behavior of these animals is in typical reflex patterns, and for each of these there are pathways of preferential discharge; but these pathways are not linked in reflex arcs as conventionally drawn. No local reflex movement can be executed without alteration of the excitatory state of an extensive field of the central nervous system. The individual reflex is set within a total pattern of central activity as part of an equilibrated dynamic system and it cannot be understood apart from the properties of this larger organization.

Passing now from salamanders to men, we are confronted with unsolved problems in the analysis of even the simplest sensory experience, as will appear from a simple illustration.

Our knowledge of the relations of things in space is derived chiefly through vision, touch and the muscular sense. Our appreciation of the lapse of time evidently comes through complex experiences, and hearing is preeminently the time-sense; sensibility of the skin ordinarily is not involved. Now, it has been found in the study of tactile sensibility of the skin that it is possible to make a very simple experiment in which judgments of space may be determined by either the spatial or the temporal component of the stimulation. This, which

Dr. Helson calles the tau effect,[10] is easily demonstrated. If three spots on the arm are touched lightly with the point of a pencil in quick succession, two intervals of space will be defined by the three stimulations. It is found that the judgments of the lengths of these intervals depends more upon the time interval between the stimulations than upon the actual distance between the places touched.

In the field of visual physiology a quite different series of experiments[11] showed that in a certain set-up of conditions it was possible to so manipulate the spatial and temporal factors as to allow time to reciprocate with space in neural activity. Here a certain kind of seen motion is maintained despite the shifting of the factors in time and space. In these and other similar instances that might be cited we have a measurable relationship between time and space such that one may be substituted for the other, and this is effected within the neural apparatus somewhere between the sense organ and the integrating apparatus of the cerebral cortex.

These experiments are cited here to show that in even the simplest acts of sense perception there are features which cannot be fitted into the conventional schemes of reflexology. And when we enter the domain of those higher cortical functions involved in abstraction and the use of symbols (as in language and mathematics) these difficulties are enormously greater. The more we learn about these processes and the related neural mechanisms the more probable it becomes that no mechanical models adequate to illuminate these mysteries can be constructed in terms of classical Newtonian mechanical principles. This does not mean that these activities are lawless or non-mechanistic. No appeal to mystic agencies is called for, but it does imply that a radical revision of traditional conceptions of the mechanism involved is essential. This is regarded as so important that I wrote a book about it.[12]

The principles of Euclidian geometry and Newtonian mechanics are applicable in the "man-sized" realm of our common experience, but they fail to fit the facts revealed by current research in subatomic physics. Here they must be supplemented by the principles of relativity and quantum mechanics. Absolute time and space are replaced by a radically different concept of space-time. So, though our "perceptual knowledge"[13] of ordinary things and events may be adequately framed within the categories of conventional mechanics, it may be that the data of "conceptual experience" and all of the nervous spparatus involved in its operation can be articulated with the rest of our scientific knowledge of nature only in terms of a radically different system of principles yet to be

[10] Harry Helson and S. M. King. The tau effect—an example of psychological relativity. *J. Exper. Psychol. 14*, 202–217 (1931).

[11] S. Howard Bartley. Visual sensation and its dependence on the neurophysiology of the optic pathway. *Biological symposia* 7, 87–106 (1942).

[12] C. Judson Herrick. The thinking machine. Univ. of Chicago Press, 1929; 2d. ed., 1932.

[13] Roy Wood Sellars. An analytic approach to the mind-body problem. *Philosophical Review 47*, 461–487 (1938).

clarified. The underlying principles of relativity,[14] for example, may have much wider reach than is commonly recognized. If this speculation has sound factual basis, our first search should be for the nexus which relates perceptual knowledge (objectified experience of the "public" world) with conceptual knowledge (subjective experience which is "private" and has no objective reference). That such a relationship exists is evident, for thinking controls conduct.

The peripheral nervous system is the apparatus through which we acquire all of our perceptual knowledge about what is going on in the world and through which we act upon environment. The central nervous system is preeminently the apparatus of integration of this experience. This is the primary vital function, without which life disintegrates, and the higher these synthesizing activities are elaborated the further they are removed within the brain from the analytic apparatus of the brain-stem. The human cerebral cortex is the culmination of differentiation in this domain.

There are intrinsic cortical functions which can be carried on independently of immediate sensorimotor experience with the flow of events going on outside. Some of these we apprehend subjectively and these events of our conceptual experience can be known in no other way. They are essentially and inevitably private. What may be the nature of the relationship between this private conceptual experience and our public perceptual knowledge about things has been for centuries the basic problem of science and philosophy. The right answer to this question is that we do not know. But it does not follow that we cannot find out, and since all of our concepts are built up from the data of sensorimotor experience, it may well be that the key to the problem will be found, as already suggested, in the analytic apparatus of the peripheral nervous system. When we know more about how a sensory excitation is actually translated into the appropriate motor response in the simplest case, we may find that the door of admittance into hitherto forbidden mysteries has been opened.

[14] Sir James Jeans. Physics and philosophy. New York, 1943.

RADIOMETRIC AND COLORIMETRIC CHARACTERISTICS OF THE BLACKBODY BETWEEN 2800°K AND 3800°K

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The standard method of giving the radiometric and colorimetric characteristics of various sources is to relate them, when possible, to those of the standard radiator, that is, the blackbody (*1*, *2*, *3*). What is the blackbody? One way of defining the blackbody is: It is a body that will absorb all the radiation that falls upon it, neither reflecting nor transmitting any of the incident radiation. It will, therefore, be black at room temperature and at any other temperature at which its radiation in the visible spectrum is inappreciable. At any temperature at which the blackbody is useful as a source of light it is certainly not black in the ordinary sense of the word. On the contrary, it radiates more energy than any other body for the same size and temperature, provided the radiation is due to temperature alone.

The Blackbody. The name "blackbody" for the standard radiator is at times misleading. This name was probably chosen because it is descriptive of the radiator when it is at room temperature and was originally written as two words; but, as the name of the standard radiator, is now written as a single word. Many illustrations may be given, such as the Faraday ice pail, α-rays, X-rays, etc., in which the descriptive part of the name has lost its original meaning, and the phrase or word has come to denote a definite physical concept.

No known substance has the radiating characteristics of a blackbody, although some, such as lampblack and some finely divided metals, approach it in certain parts of the spectrum; but it can be shown that an enclosure with opaque walls at uniform temperature, and of finite emissivity at all wavelengths, contains blackbody radiation of the same temperature as that of the walls. If a small hole is made in the walls the radiation which escapes will approximate that of a blackbody. Benford (*3*) has shown that for a hole 1% of the area of the enclosure and wall emissivity of 50%, the escaping radiation is more than 99% of that of a blackbody; with an emissivity greater than 90% or a hole less than 0.1% of the area of the enclosure, the escaping radiation will be 99.9% or more of that of a blackbody.

Benford (*3*) had the problem presented of making a determination of the emissivity of the human skin for its own radiation. The human body maintains an absolute temperature of approximately 310°K and from the radiating characteristics of the blackbody it may be shown that 25% of the radiation at this temperature is for radiation at wavelengths shorter than 9.3μ and that 67.5% is

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of wavelengths shorter than 17μ. The skin therefore does most of its radiating in the region from 6μ to 20μ, a region difficult to explore when dealing with such a low-temperature radiator. Benford found an absurdly simple solution for this problem: he put his receiving instrument, a thermopile, in a blackbody which consisted of a box so diaphragmed that the only radiation that could reach the thermopile from the outside was through a small opening. First the hand was held over the opening so that the thermopile received radiation only from the hand; next a cavity was made by two hands with a small opening, and this small opening held over the opening in the box containing the thermopile, which thus received blackbody radiation corresponding to the temperature of the human skin. The ratio of the two responses of the thermopile gave the emissivity of the human skin, which Benford found to be slightly over 90%. Both readings are, of course, reduced by the back radiation from the thermopile and its diaphragms, but the factor proves to be the same for the two, so that their ratio gives the emissivity of human skin.

The Planck Radiation Law. The blackbody owes its value to the fact that its radiating characteristics depend on temperature alone. The Planck equation giving this relation is

$$W_\lambda = \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1} \tag{1}$$

where W_λ is the radiant flux per unit area per unit wavelength interval, λ the wavelength, T the absolute temperature, e the base of the Napierian logarithms and c_1 and c_2 constants. This equation for the spectral distribution of blackbody radiation is well supported by both theory and experiment, for a wide range of temperature and wavelength and is the formula used for calculating the spectral distribution and colorimetric characteristics of the blackbody.

The cavity blackbody gives an interesting illustration of the limitations on optical means of increasing the brightness of illuminated surfaces. The statement is often made that if a single lamp gives a certain illumination on a surface, two will give twice as much, etc., and the conclusion is sometimes implied that practically any brightness desired can be reached by this method. The attainable brightness is, however, definitely limited—the limit depending on whether the optical arrangement used does or does not return significant amounts of radiation to the source. In the latter case, the brightness will be limited to that of the filaments of the lamps used. Even this limit would require that the entire solid angle of a hemisphere be filled by reflector lamps with perfectly reflecting surfaces and perfectly transparent cover glasses. In the former case, the limit would be set by that of a small area inside a sphere made up entirely of heated filaments, namely the brightness of a blackbody at the filament temperature, since this arrangement is, by definition, a cavity blackbody. The blackbody brightness is approximately twice that of a freely radiating tungsten surface.

There have been published several tables of the calculated spectral distribution of the radiation of the blackbody, notably by Skogland (*4*) and by Moon

(*5*). Skogland (using $c_2 = 14330$) gives data at 20° intervals from 2000°K to 3120°K; Moon gives data at 100° intervals from 3500°K to 8000°K (with $c_2 = 14320$). The colorimetric tables of the International Commission on Illumination, given by Judd (*2*), are based on $c_2 = 14350$ micron degrees.

· The gap between Skogland's highest and Moon's lowest temperature is particularly inconvenient in the field of tungsten-filament incandescent lamps, because several general service lamps (*1*) and practically all of the lamps designed for photographic use (*6*) have color temperatures in this range. Thus, for our use and that of the Colorimetry Committee of the Optical Society of America, we have made calculations, (given in Table II) by 100° intervals, from 2800°K to 3800°K. In order to be consistent with published colorimetric data (*2*), we have used $c_2 = 14350$, although a recent review of the radiation constants by Wensel (*7*) indicates that 14360 micron degrees is the value in best agreement with all the published experimental data. The determination of the radiation constants with a precision sufficient to warrant a recalculation of existing tables to a single basis would be a great service to pyrometry, radiometry and colorimetry.

Because of the uncertainty of the radiation constants, the multiplication by the first radiation constant has not been made, but a factor of 10^6 has been used to avoid non-significant zeros. The value of c_1 consistent with the I.C.I. value of c_2 (14350 μ deg K = 1.4350 cm deg K) is 3.7313×10^{-12} watt cm². Since in the Planck equation c_2 and T appear only as their ratio in the exponent ($e^{-\frac{c_2}{\lambda T}}$), the table can be used for another value of c_2 by changing the temperature in the same ratio, as for example, the tabular value for 3000°K and $c_2 = 14350$, applies to a temperature of 3002.1°K for $c_2 = 14360$.

In much radiometric and colorimetric work only relative values are needed. For example, colorimetric distribution data for sources are customarily normalized to $Y = 100\ 000$; and spectral distribution data for sources may be given in such a way that the luminous intensities of all sources have the same value, or the intensities may be equated at some one wavelength. However, if absolute values are desired, care must be taken that the c_1 and c_2 used are in the same units. Also it must be remembered that c_1 and c_2 are related as follows:

$$c_1 = 2\pi c c_2 k \tag{2}$$

where c is the velocity of light and k is the Boltzmann constant.

The Spectral Radiancy of the Blackbody. From equation (1), for sufficiently small values of the product λT the exponential $e^{\frac{c_2}{\lambda T}}$ becomes very large, and the term -1 can be neglected in comparison with it. This approximation is the Wien radiation equation

$$W_\lambda \doteq c_1 \lambda^{-5} e^{-\frac{c_2}{\lambda T}} \tag{3}$$

For λT less than 3000 micron degrees, the formula gives values of W_λ that are within one percent of those given by the Planck equation.

For logarithmic calculation (*8*), the Wien equation may be written

$$W_\lambda \doteq c_1 \lambda^{-5} 10^{-\frac{c_2 \lg e}{\lambda T}} \tag{4}$$

whence

$$\lg W_\lambda \doteq \lg c_1 - 5 \lg \lambda - \frac{c_2 \lg e}{\lambda T} \tag{5}$$

When the difference between the Wien and Planck equations becomes significant, a small correction is necessary. A table (unpublished) of the logarithmic correction as a function of $\frac{c_2 \lg e}{\lambda T}$ has been used.

As an indication of the magnitude of this correction for various values of λT, and of the necessity of making it, values are given in Table I for a few rounded values of the product λT. The correction of course depends upon the value used for c_2. In comparing with other tables, it must be remembered that c_2 is here taken as 14350 μ deg K. The values in the table show that for λT =

TABLE I

λT (μ°K)	$(W_\lambda)_P/(W_\lambda)_W$
1000	1.000 000 6
1500	1.000 07
2000	1.000 8
2500	1.003 2
3000	1.008 4
4000	1.027 7
5000	1.056 7

2500 μ deg K, the correction is a little less than $\frac{1}{3}$%, and decreases very rapidly for smaller values of λT. For larger values of λT than 2500, the correction will be necessary for most work.

The 1931 I.C.I. Standard Observer for Colorimetry. If the eye were a perfect analyzing instrument, none of the commercial light sources could be matched by eye observation with the blackbody. It is found, however, that three specifications are sufficient to define the colorimetric properties of a light source, filter or reflecting surface. Many choices of three specifications are possible, but international agreement has been reached on a particular set, defined by the 1931 I.C.I. Standard Observer (*2, 9*). In this system, the spectral radiant intensity, spectral radiant flux, spectral transmittance, or spectral reflectance, is to be multiplied by three "distribution coefficients" designated as $\bar{x}$, $\bar{y}$ and $\bar{z}$, and sums or averages taken over the entire visible spectrum. Thus for any source, these summations give "tristimulus values":

$$\begin{aligned} X &= \Sigma \bar{x} J_\lambda \\ Y &= \Sigma \bar{y} J_\lambda \\ Z &= \Sigma \bar{z} J_\lambda \end{aligned} \tag{6}$$

TABLE II

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 2800°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED $\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	175.32	.25		1.14	1		5
390	217.57	.91	.02	4.37	4	0	21
400	266.26	3.81	.11	18.08	18	1	87
410	321.66	13.99	.39	66.71	67	2	320
420	383.99	51.61	1.54	247.90	248	7	1 190
430	453.40	128.72	5.26	628.23	618	25	3 016
440	529.91	184.57	12.19	925.81	886	59	4 445
450	613.49	206.26	23.31	1 087.2	990	112	5 220
460	704.05	204.74	42.24	1 175.2	983	203	5 642
470	801.42	156.60	72.93	1 031.9	752	350	4 954
480	905.32	86.55	125.84	736.02	416	604	3 534
490	1 015.5	32.50	211.21	472.39	156	1 014	2 268
500	1 131.5	5.54	365.47	307.77	27	1 755	1 478
510	1 253.0	11.65	630.25	198.22	56	3 026	952
520	1 379.4	87.31+	979.38	107.87	419	4 702	518
530	1 510.4	249.98	1 302.0	63.74	1 200	6 251	306
540	1 645.4	477.84	1 569.7	33.40	2 294	7 536	160
550	1 784.0	773.18	1 775.0	15.52	3 712	8 522	75
560	1 925.5	1 144.7	1 915.8	7.51	5 496	9 198	36
570	2 069.4	1 577.1	1 970.1	4.35	7 572	9 459	21
580	2 215.1	2 029.7	1 927.2	3.77	9 745	9 253	18
590	2 362.3	2 424.4	1 788.3	2.60	11 640	8 586	12
600	2 510.3	2 666.4	1 584.0	2.01	12 802	7 605	10
610	2 658.6	2 665.6	1 337.3	.80	12 798	6 421	4
620	2 806.9	2 398.2	1 069.4	.56	11 514	5 134	3
630	2 954.5	1 898.0	782.94		9 113	3 759	
640	3 100.9	1 388.9	542.66		6 668	2 605	
650	3 246.0	920.24	347.32		4 418	1 668	
660	3 389.2	558.88	206.74		2 683	993	
670	3 530.3	308.55	112.97		1 481	542	
680	3 668.7	171.70	62.37		824	299	
690	3 804.3	86.36	31.19+		415	150	
700	3 936.8	44.88	16.14		216−	78	
710	4 065.9	23.58	8.54		113	41	
720	4 191.4	12.16	4.19		58	20	
730	4 313.1	6.04	2.16		29	10	
740	4 430.9	3.10	1.33		15	6	
750	4 544.4	1.36	.45		7	2	
760	4 653.8	.93	.46+		5−	2	
Σ	—	23 006.79	20 828.40	7 143.07	110 459	100 000	34 295

Trichromatic coefficients: $x = .45131$; $y = .40857$; $z = .14012$.

* Actually $10^6 W_\lambda / c_1$, etc., on account of the uncertainty of the radiation constants.

† These values have been normalized by division by $10^{-5}\Sigma\bar{y}W_\lambda$*, i.e., $\Sigma\bar{y}W_\lambda$† has been made 100 000.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 2900°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED $\bar{x}W_\lambda$†	NORMALIZED $\bar{y}W_\lambda$†	NORMALIZED $\bar{z}W_\lambda$†
380	279.12	.39	—	1.81	1	—	6
390	342.29	1.44	.03	6.88	5	0	24
400	414.17	5.92	.17	28.12	21	1	99
410	494.99	21.53	.59	102.66	76	2	361
420	584.87	78.61	2.34	377.59	277	8	1 329
430	683.86	194.15	7.93	947.57	683	28	3 335
440	791.84	275.80	18.21	1 383.4	971	64	4 869
450	908.59	305.47	34.53	1 610.1	1 075	122	5 667
460	1 033.9	300.64	62.03	1 725.7	1 058	218	6 074
470	1 167.2	228.08	106.22	1 502.9	803	374	5 290
480	1 308.3	125.07	181.85	1 063.6	440	640	3 744
490	1 456.5	46.61	302.95	677.56	164	1 066	2 385
500	1 611.2	7.90	520.42	438.25	28	1 832	1 543
510	1 771.9	16.48	891.27	280.32	58	3 137	987
520	1 937.8	122.66	1 375.8	151.53	432	4 842	533
530	2 108.2	348.92	1 817.3	88.97	1 228	6 396	313
540	2 282.6	662.87	2 177.6	46.34	2 333	7 664	163
550	2 460.1	1 066.2	2 447.8	21.40	3 753	8 615+	75
560	2 640.0	1 569.5	2 626.8	10.30	5 524	9 245+	36
570	2 821.7	2 150.4	2 686.3	5.92+	7 569	9 455	21
580	3 004.4	2 753.0	2 613.8	5.11	9 690	9 200	18
590	3 187.5	3 271.3	2 413.0	3.51	11 514	8 493	12
600	3 370.3	3 580.0	2 126.7	2.70	12 600	7 485	10−
610	3 552.3	3 561.6	1 786.8	1.06+	12 536	6 289	4
620	3 732.9	3 189.4	1 422.2	.75	11 226	5 006	3
630	3 911.5	2 512.8	1 036.5		8 844	3 648	
640	4 087.5	1 830.8	715.32		6 444	2 518	
650	4 260.6	1 207.9	455.88		4 251	1 605	
660	4 430.5	730.58	270.26		2 571	951	
670	4 596.4	401.73	147.09		1 414	518	
680	4 758.3	222.69	80.89		784	285	
690	4 915.5	111.58	40.31		393	142	
700	5 068.4	57.78	20.78		203	73	
710	5 216.1	30.25	10.95		106	39	
720	5 358.7	15.54	5.36		55	19	
730	5 495.8	7.69	2.75		27	10	
740	5 627.4	3.94	1.69		14	6	
750	5 753.6	1.73	.58		6	2	
760	5 874.1	1.17	.59		4	2	
Σ		31 020.12	28 411.59	10 484.05	109 181	100 000	36 901

Trichromatic coefficients: $x = .44368$; $y = .40637$; $z = .14995+$.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3000°K*

WAVE-LENGTH mμ	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED $\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	430.82	.60	—	2.80	2	—	7
390	522.49	2.19	.05	10.50	6	0	28
400	625.55	8.95	.25	42.48	24	1	112
410	740.15	32.20	.89	153.51	85	2	404
420	866.20	116.42	3.46	559.22	307	9	1 472
430	1 003.6	284.92	11.64	1 390.6	750	31	3 661
440	1 152.0	401.23	26.50	2 012.6	1 056	70	5 299
450	1 310.9	440.72	49.81	2 323.0	1 160	131	6 116
460	1 479.7	430.30	88.78	2 470.0	1 133	234	6 504
470	1 658.0	323.97	150.88	2 134.8	853	397	5 621
480	1 844.8	176.36	256.43	1 499.8	464	675	3 949
490	2 039.4	65.26	424.20	948.75	172	1 117	2 498
500	2 240.9	10.98	723.82	609.54	29	1 906	1 605
510	2 448.6	22.77	1 231.6	387.36	60	3 243	1 020
520	2 661.2	168.45	1 889.4	208.10	444	4 975	548
530	2 878.1	476.32	2 480.9	121.45	1 254	6 532	320
540	3 098.1	899.70	2 955.6	62.89	2 369	7 782	166
550	3 320.6	1 439.1	3 303.9	28.89	3 789	8 699	76
560	3 544.4	2 107.1	3 526.6	13.82	5 548	9 286	36
570	3 768.9	2 872.2	3 588.0	7.91	7 562+	9 447	21
580	3 992.9	3 658.7	3 473.8	6.79	9 633	9 147	18
590	4 216.0	4 326.8	3 191.5	4.64	11 392+	8 403	12
600	4 437.1	4 713.1	2 799.8	3.55	12 410	7 372	9
610	4 655.8	4 667.9	2 341.9	1.40	12 291	6 166	4
620	4 871.1	4 161.9	1 855.9	.97	10 958	4 887	3
630	5 082.8	3 265.1	1 346.9		8 597	3 546	
640	5 289.9	2 369.4	925.74		6 239	2 437	
650	5 492.2	1 557.0	587.67		4 100	1 547	
660	5 689.2	938.14	347.04		2 470	914	
670	5 880.4	513.95	188.17		1 353	495	
680	6 065.7	283.88	103.12		747	272	
690	6 244.2	141.75	51.20		373	135	
700	6 416.5	73.15	26.31		193	69	
710	6 581.9	38.18	13.82		101	36	
720	6 740.2	19.55	6.74		51	18	
730	6 891.1	9.65	3.45		25	9	
740	7 034.9	4.92	2.11		13	6	
750	7 171.3	2.15	.72		6	2	
760	7 300.3	1.46	.73		4	2	
Σ		41 026.42	37 979.33	15 005.37	108 023	100 000	39 509

Trichromatic coefficients: $x = .43640$; $y = .40399$; $z = .15961$.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3100°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED		
					$\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	646.62	.91	—	4.20	2	—	8
390	776.07	3.26	.08	15.60	7	0	31
400	920.00	13.16	.37	62.47	26	1	125
410	1 078.4	46.91	1.29	223.66	94	3	449
420	1 250.8	168.10	5.00	807.50	337	10	1 620
430	1 436.8	407.92	16.67	1 990.9	818	33	3 994
440	1 635.8	569.76	37.62	2 858.0	1 143	75	5 733
450	1 847.1	620.98	70.19	3 273.2	1 246	141	6 566
460	2 069.6	601.82	124.17	3 454.5	1 207	249	6 930
470	2 302.3	449.86	209.51	2 964.4	902	420	5 947
480	2 544.3	243.23	353.66	2 068.5	488	709	4 149+
490	2 794.5	89.42	581.25	1 300.0	179	1 166	2 608
500	3 051.1	14.95	985.51	829.91	30	1 977	1 665
510	3 313.7	30.82	1 666.8	524.23	62	3 344	1 052
520	3 580.7	226.66	2 542.3	280.01	455	5 100	562
530	3 850.8	637.31	3 319.4	162.50	1 278	6 659	326
540	4 123.1	1 197.3	3 933.4	83.70	2 402	7 891	168
550	4 396.2	1 905.3	4 374.2	38.25	3 822	8 775	77
560	4 669.2	2 775.8	4 645.8	18.21	5 568	9 320	36+
570	4 941.0	3 765.5	4 703.8	10.37+	7 554	9 436	21
580	5 210.4	4 774.3	4 533.0	8.86	9 578	9 093+	18
590	5 476.7	5 620.7	4 145.9	6.02	11 276	8 317	12
600	5 738.9	6 095.9	3 621.3	4.59	12 229	7 265	9
610	5 996.4	6 012.0	3 016.2	1.80	12 061	6 051	4
620	6 248.4	5 338.6	2 380.6	1.25	10 710	4 776	3
630	6 494.3	4 172.0	1 721.0		8 369	3 452	
640	6 733.2	3 015.8	1 178.3		6 050	2 364	
650	6 964.8	1 974.5	745.23		3 961	1 495	
660	7 189.0	1 185.5	438.53		2 378	880	
670	7 404.9	647.19	236.96		1 298	475	
680	7 612.4	356.26	129.41		715	260	
690	7 811.1	177.31	64.05		356	128	
700	8 000.9	91.21	32.80		183	66	
710	8 181.8	47.45+	17.18		95	34	
720	8 353.5	24.22	8.35		49	17	
730	8 516.1	11.92	4.26		24	9	
740	8 668.8	6.07	2.60		12	5	
750	8 812.9	2.64	.88		5	2	
760	8 947.5	1.79	.90		4	2	
Σ		53 324.33	49 848.47	20 992.63	106 973	100 000	42 113

Trichromatic coefficients: x = .42946; y = .40147 z = .16907.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3200°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED $\bar{x}W_\lambda$†	NORMALIZED $\bar{y}W_\lambda$†	NORMALIZED $\bar{z}W_\lambda$†
380	946.19	1.32	—	6.15	2	—	10
390	1 124.6	4.72	.11	22.60	7	0	35
400	1 320.9	18.89	.53	89.69	29	1	139
410	1 534.6	66.76	1.84	318.28	104	3	495
420	1 765.1	237.22	7.06	1 139.5	369	11	1 771
430	2 011.5	571.04	23.33	2 787.1	888−	36	4 331
440	2 272.6	791.55	52.27	3 970.5	1 230	81	6 170
450	2 547.4	856.45	96.80	4 514.3	1 331	150	7 016
460	2 834.4	824.23	170.06	4 731.2	1 281	264	7 353
470	3 132.1	612.01	285.02	4 032.9	951	443	6 267
480	3 439.2	328.79	478.06	2 796.1	511−	743	4 345
490	3 754.1	120.13	780.84	1 746.4	187	1 213	2 714
500	4 075.0	19.97	1 316.2	1 108.4	31	2 045	1 722+
510	4 400.7	40.93	2 213.6	696.19	64	3 440	1 082
520	4 729.3	299.36	3 357.8	369.84	465	5 218	575
530	5 059.5	837.36	4 361.3	213.51	1 301	6 778	332
540	5 390.0	1 565.3	5 142.1	109.42	2 433	7 991	170
550	5 719.1	2 478.7	5 690.5	49.76	3 852	8 843	77
560	6 045.7	3 594.2	6 015.5	23.58	5 586	9 349−	37
570	6 368.8	4 853.7	6 063.2	13.37+	7 543	9 423	21
580	6 686.8	6 127.2	5 817.5	11.37	9 522	9 041	18
590	6 999.2	7 183.2	5 298.5	7.70	11 163	8 234	12
600	7 304.5	7 758.9	4 609.1	5.84	12 058	7 163	9
610	7 602.2	7 622.0	3 823.9	2.28	11 845	5 943	4
620	7 891.5	6 742.5	3 006.6	1.58	10 478	4 672	2
630	8 171.8	5 249.6	2 165.6		8 158	3 365	
640	8 442.3	3 781.3	1 477.4		5 876	2 296	
650	8 702.8	2 467.2	931.19		3 834	1 447	
660	8 952.6	1 476.3	546.11		2 294	849	
670	9 191.8	803.36	294.14		1 249−	457	
680	9 419.3	440.83	160.13		685	249	
690	9 635.6	218.73	79.01		340	123	
700	9 840.8	112.18	40.35		174	63	
710	10 034.	58.20	21.07		90	33	
720	10 216.	29.63	10.22		46	16	
730	10 386.	14.54	5.19		23	8	
740	10 545.	7.38	3.17−		12−	5	
750	10 692.	3.21	1.07		5	2	
760	10 829.	2.16+	1.08		3	2	
Σ		68 221.05−	64 347.45+	28 767.56	106 020	100 000	44 707

Trichromatic coefficients: x = .42285+; y = .39884; z = .17831.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3300°K*

WAVE-LENGTH mμ	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED		
					$\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	1 352.9	1.89	—	8.79	2	—	11
390	1 593.4	6.69	.16	32.03	8	0	39
400	1 855.2	26.53	.74	125.97	32	1	154
410	2 137.7	92.99	2.56+	443.35	114	3	542
420	2 439.4	327.85	9.76	1 574.9	401	12	1 925
430	2 759.1	783.30	32.01	3 823.0	957	39	4 673
440	3 095.0	1 078.0	71.18	5 407.3	1 318	87	6 609
450	3 445.5	1 158.4	130.93	6 105.8	1 416	160	7 463
460	3 808.5	1 107.5	228.51	6 357.1	1 354	279	7 770
470	4 182.4	817.22	380.59	5 385.2	999	465	6 582
480	4 564.8	436.40	634.51	3 711.2	533	776	4 536
490	4 953.9	158.53	1 030.4	2 304.6	194	1 259	2 817
500	5 347.7	26.21−	1 727.3	1 454.6	32	2 111	1 778
510	5 744.5	53.42	2 889.5	908.78	65	3 532	1 111
520	6 142.0	388.79	4 360.8	480.31	475	5 330	587
530	6 538.7	1 082.2	5 636.4	275.93	1 323	6 889	337
540	6 932.8	2 013.3	6 613.9	140.74	2 461	8 084	172
550	7 322.7	3 173.7	7 286.0	63.71	3 879	8 905	78
560	7 706.9	4 581.7	7 668.3	30.06	5 600	9 373	37
570	8 084.3	6 161.0	7 696.3	16.98	7 530	9 407	21
580	8 453.4	7 745.9	7 354.4	14.37	9 467	8 989	17+
590	8 812.9	9 044.6	6 671.4	9.69	11 055	8 154	12
600	9 162.4	9 732.4	5 781.5	7.33	11 895+	7 067−	9
610	9 500.8	9 525.5	4 778.9	2.85	11 643	5 841	3
620	9 827.2	8 396.3	3 744.1	1.96+	10 262	4 576	2
630	10 141.	6 514.6	2 687.4		7 963	3 285	
640	10 442.	4 676.8	1 827.3		5 716	2 233	
650	10 729.	3 041.6	1 148.0		3 718	1 403	
660	11 002.	1 814.3	671.14		2 218	820	
670	11 262.	984.26	360.37		1 203	440	
680	11 507.	538.52	195.61		658	239	
690	11 737.	266.43	96.24		326	118	
700	11 953.	136.27	49.01		167	60	
710	12 155.	70.50	25.53		86	31	
720	12 343.	35.80	12.34		44	15	
730	12 517.	17.52	6.26		21	8	
740	12 677.	8.87	3.80		11	5	
750	12 823.	3.85	1.28		5	2	
760	12 955.	2.59	1.30		3	2	
Σ		86 032.23	81 815.73	38 686.55	105 154	100 000	47 285

Trichromatic coefficients: x = .41655; y = .39614; z = .18731.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3400°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED		
					$\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	1 894.3	2.65	—	12.31	3	—	12
390	2 211.8	9.29	.22	44.46	9	0	43
400	2 554.2	36.53	1.02	173.43	36	1	169
410	2 920.2	127.03	3.51−	605.65	124	3	590
420	3 307.8	444.57	13.23	2 135.5	433	13	2 082−
430	3 714.8	1 054.6	43.09	5 147.3	1 028	42	5 017
440	4 139.1	1 441.7	95.20	7 231.5	1 405	93	7 048
450	4 578.1	1 539.2	173.97	8 113.0	1 500	170	7 908
460	5 029.3	1.462.5	301.76	8 395.0	1 425	294	8 182
470	5 490.5	1 072.8	499.63	7 069.5	1 046	487	6 891−
480	5 958.7	569.65	828.27	4 844.4	555	807	4 722
490	6 431.8	205.82	1 337.8	2 992.1	201	1 304	2 916
500	6 906.9	33.84	2 230.9	1 878.7	33	2 174	1 831
510	7 382.3	68.66	3 713.3	1 167.9	67	3 619	1 138
520	7 855.2	497.23	5 577.2	614.29	485	5 436	599
530	8 323.8	1 377.6	7 175.1	351.26	1 343	6 993	342
540	8 786.4	2 551.6	8 382.2	178.37	2 487	8 170	174
550	9 240.6	4 004.9	9 194.3	80.39	3 903	8 962−	78
560	9 685.2	5 757.8	9 636.7	37.77	5 612	9 393	37
570	10 119.	7 711.7	9 633.4	21.25	7 516	9 389	21
580	10 540.	9 658.1	9 170.0	17.92	9 414	8 938	18−
590	10 948.	11 236.	8 287.8	12.04	10 951	8 078	12
600	11 341.	12 047.	7 156.3	9.07	11 742	6 975	9
610	11 719.	11 750.	5 894.8	3.52	11 452	5 746	3
620	12 081.	10 322.	4 602.8	2.42	10 061	4 486	2
630	12 426.	7 982.7	3 293.0		7 781	3 210	
640	12 754.	5 712.7	2 232.0		5 568	2 176−	
650	13 065.	3 704.0	1 398.0		3 610	1 363	
660	13 359.	2 202.9	814.89		2 147	794	
670	13 635.	1 191.7	436.30		1 161+	425	
680	13 892.	650.17	236.17		634	230	
690	14 133.	320.81	115.89		313	113	
700	14 356.	163.65	58.86		160	57	
710	14 561.	84.46−	30.58		82	30	
720	14 750.	42.77	14.75		42	14	
730	14 921.	20.89	7.46		20	7	
740	15 076.	10.55	4.52		10	4	
750	15 215.	4.56	1.52		4	2−	
760	15 339.	3.07	1.53		3	2	
Σ	•	107 077.70	102 597.97	51 139.05	104 366	100 000	49 844

Trichromatic coefficients: x = .41055; y = .39338−; z = .19607.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3500°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED		
					$\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	2 601.8	3.64	—	16.91	3	—	13
390	3 013.1	12.66	.30	60.56	10	0	48
400	3 452.9	49.38	1.38	234.45	39	1	184+
410	3 918.9	170.47	4.70	812.77	134	4	640
420	4 407.9	592.42	17.63	2 845.7	466	14	2 240
430	4 917.5	1 399.2	57.04	6 813.7	1 101	45	5 363
440	5 444.3	1 896.2	125.22	9 511.8	1 493	99	7 487
450	5 985.2	2 012.2	227.44	10 606.	1 584	179	8 348
460	6 537.2	1 901.0	392.23	10 912.	1 496	309	8 589
470	7 096.8	1 386.7	645.80	9 137.8	1 092	508	7 193
480	7 661.1	732.40	1 064.9	6 228.4	576	838	4 903
490	8 227.0	263.26	1 711.2	3 827.2	207	1 347	3 012+
500	8 791.6	43.08	2 839.7	2 391.3	34	2 235	1 882
510	9 352.1	86.97	4 704.1	1 479.5	68	3 703	1 165
520	9 906.3	627.06	7 033.5	774.68	494	5 536	610
530	10 452.	1 729.7	9 009.3	441.01	1 362	7 092	347
540	11 037.	3 190.4	10 481.	223.02	2 511	8 250	176
550	11 507.	4 987.4	11 450.	100.12	3 926	9 013	79
560	12 014.	7 142.3	11 954.	46.85	5 622	9 409	37
570	12 505.	9 529.9	11 905.	26.26	7 501	9 371	21
580	12 978.	11 892.	11 291.	22.06	9 361	8 888	17
590	13 433.	13 786.	10 169.	14.78	10 852	8 004	12
600	13 868.	14 731.	8 750.8	11.10	11 595	6 888	9
610	14 283.	14 320.	7 184.4	4.28	11 272	5 655	3
620	14 678.	12 541.	5 592.2	2.94	9 872	4 402	2
630	15 051.	9 669.0	3 988.6		7 611	3 140	
640	15 403.	6 899.1	2 695.6		5 431	2 122	
650	15 733.	4 460.4	1 683.4		3 511	1 325	
660	16 042.	2 645.3	978.57		2 082	770	
670	16 329.	1 427.1	522.52		1 123	411	
680	16 594.	776.62	282.10		611	222	
690	16 838.	382.23	138.07		301	109	
700	17 061.	194.49	69.96		153	55	
710	17 264.	100.13	36.25+		79	29	
720	17 447.	50.60	17.45		40	14	
730	17 610.	24.65	8.81		19	7	
740	17 755.	12.43	5.33		10	4	
750	17 880.	5.36	1.79		4	1	
760	17 989.	3.60	1.80		3	1	
Σ		131 677.35	127 042.09	66 545.19	103 649	100 000	52 380

Trichromatic coefficients: x = .40483; y = .39058; z = .20459.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3600°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED		
					$\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	3 511.1	4.92	—	22.82	3	—	15
390	4 035.2	16.95	.40	81.11	11	0	52
400	4 590.5	65.64	1.84	311.70	42	1	200
410	5 173.7	225.06	6.21	1 073.0	145	4	690
420	5 781.0	776.96	23.13−	3 732.2	500	15	2 400
430	6 408.8	1 819.4	74.34	8 880.1	1 170	48	5 711
440	7 052.9	2 456.5	162.22	12 322.	1 580	104	7 925−
450	7 709.2	2 591.9	292.95	13 662.	1 667	188	8 786
460	8 373.9	2 435.1	502.44	13 978.	1 566	323	8 990−
470	9 042.9	1 767.0	822.91	11 644.	1 136	529	7 488
480	9 712.9	928.56	1 350.1	7 896.6	597	868	5 078
490	10 380.	332.16	2 159.0	4 828.8	214	1 388	3 106−
500	11 041.	54.10	3 566.2	3 003.2	35	2 294−	1 931
510	11 693.	108.75	5 881.7	1 849.9	70	3 783	1 190
520	12 332.	780.64	8 756.1	964.41	502	5 631	620
530	12 958.	2 144.6	11 170.	546.84	1 379	7 184	352
540	13 567.	3 939.8	12 943.	275.40	2 534	8 324	177
550	14 157.	6 135.6	14 086.	123.17	3 946	9 059	79
560	14 726.	8 754.5	14 652.	57.43	5 630	9 423	37
570	15 273.	11 639.	14 540.	32.07	7 485	9 351	21
580	15 797.	14 475.	13 744.	26.85+	9 309	8 839	17
590	16 299.	16 725.	12 337.	17.93	10 756	7 934	12
600	16 771.	17 815.	10 583.	13.42	11 457	6 806	9
610	17 220.	17 265.	8 661.8	5.17	11 103	5 571	3
620	17 643.	15 074.	6 721.9	3.53	9 694	4 323	2
630	18 040.	11 589.	4 780.6		7 453	3 075−	
640	18 409.	8 245.6	3 221.7		5 303	2 072	
650	18 753.	5 316.4	2 006.6		3 419	1 291−	
660	19 070.	3 144.7	1 163.3		2 023−	748	
670	19 362.	1 692.3	619.60		1 088	398	
680	19 629.	918.65	333.70		591	215	
690	19 870.	451.05	162.93		290	105	
700	20 086.	228.98	82.35		147	53	
710	20 280.	117.62	42.59		76	27	
720	20 449.	59.30	20.45		38	13	
730	20 597.	28.84	10.30		19	7	
740	20 722.	14.51	6.22		9	4	
750	20 828.	6.25	2.08		4	1	
760	20 912.	4.18	2.09		3	1	
Σ		160 148.52	155 492.75	85 351.65	102 994	100 000	54 891

Trichromatic coefficients: x = .39938; y = .38777; z = .21285+.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3700°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED		
					$\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	4 662.1	6.53	—	30.30	3	—	16
390	5 319.0	22.34	.53	106.91	12	0	57
400	6 009.4	85.93+	2.40	408.04	46	1	217
410	6 728.5	292.69	8.07	1 395.5	155	4	741
420	7 471.5	1 004.2	29.89	4 823.6	533	16	2 562
430	8 233.8	2 337.5	95.51	11 409.	1 241	51	6 059
440	9 009.7	3 138.1	207.22	15 741.	1 667	110	8 360
450	9 794.9	3 293.1	372.20	17 358.	1 749	198	9 219
460	10 584.	3 077.8	635.04	17 667.	1 635	337	9 383
470	11 373.	2 222.3	1 035.0	14 644.	1 180	550	7 777
480	12 157.	1 162.3	1 689.9	9 883.9	617	898	5 249
490	12 933.	413.87	2 690.1	6 016.6	220	1 429	3 195
500	13 697.	67.12	4 424.1	3 725.6	36	2 350	1 979
510	14 445.	134.34	7 265.7	2 285.2	71	3 859	1 214
520	15 173.	960.46	10 773.	1 186.6	510	5 722	630
530	15 881.	2 628.3	13 689.	670.16	1 396	7 270	356
540	16 565.	4 810.4	15 803.	336.26	2 555	8 393	179
550	17 223.	7 464.3	17 136.	149.84	3 964	9 101	80
560	17 853.	10 614.	17 764.	69.63	5 637	9 434	37
570	18 454.	14 064.	17 569.	38.75	7 469	9 331	21
580	19 025.	17 433.	16 552.	32.34	9 259	8 791	17
590	19 566.	20 081.	14 812.	21.52	10 665	7 867	11
600	20 075.	21 324.	12 667.	16.06	11 325	6 727	9
610	20 552.	20 606.	10 338.	6.17	10 944	5 490+	3
620	20 997.	17 940.	7 999.8	4.20	9 528	4 249	2
630	21 411.	13 755.	5 674.0		7 305	3 013	
640	21 792.	9 760.7	3 813.6		5 184	2 025	
650	22 142.	6 277.3	2 369.2		3 334	1 258	
660	22 462.	3 703.9	1 370.2		1 967	728	
670	22 750.	1 988.4	728.01		1 056	387	
680	23 010.	1 076.9	391.17		572	208	
690	23 239.	527.53	190.56		280	101	
700	23 441.	267.23	96.11		142	51	
710	23 616.	136.97	49.59		73	26	
720	23 765.	68.92	23.77−		37	13	
730	23 889.	33.44	11.94		18	6	
740	23 987.	16.79	7.20		9	4	
750	24 063.	7.22	2.41		4	1	
760	24 116.	4.82	2.41		3	1	
Σ		192 808.70	188 288.63	108 026.18	102 401	100 000	57 373

Trichromatic coefficients: x = .39419; y = .38495+; z = .22086.

TABLE II—*Continued*

Spectral Radiancy and Colorimetric Distribution Data for the Blackbody at 3800°K*

WAVE-LENGTH $m\mu$	W_λ*	$\bar{x}W_\lambda$*	$\bar{y}W_\lambda$*	$\bar{z}W_\lambda$*	NORMALIZED $\bar{x}W_\lambda$†	$\bar{y}W_\lambda$†	$\bar{z}W_\lambda$†
380	6 098.4	8.54	—	39.64	4	—	18
390	6 910.3	29.02	.69	138.90	13	0	62
400	7 756.2	110.91	3.10	526.65	49	1	233
410	8 630.6	375.43	10.36	1 790.0	166	5	793
420	9 527.1	1 280.4	38.11	6 150.6	567	17	2 724
430	10 440.	2 963.9	121.10	14 466.	1 313	54	6 407+
440	11 362.	3 957.5	261.34	19 851.	1 753	116	8 793
450	12 289.	4 131.6	466.98	21 778.	1 830	207	9 646
460	13 214.	3 842.6	792.85	22 057.	1 702	351	9 770
470	14 133.	2 761.5	1 286.1	18 197.	1 223	570	8 060
480	15 039.	1 437.7	2 090.5	12 227.	637	926	5 416
490	15 930.	509.75	3 313.4	7 410.5	226	1 468	3 282
500	16 800.	82.32	5 426.4	4 569.6	36	2 404	2 024
510	17 647.	164.11	8 876.3	2 791.7	73	3 932	1 237
520	18 466.	1 168.9	13 111.	1 444.0	518	5 807	640
530	19 256.	3 186.9	16 599.	812.61	1 412	7 352	360
540	20 014.	5 812.1	19 093.	406.28	2 574	8 457	180
550	20 738.	8 987.7	20 634.	180.42	3 981	9 140	80
560	21 426.	12 738.	21 319.	83.56	5 642	9 443	37
570	22 078.	16 826.	21 018.	46.36	7 453	9 310	21
580	22 692.	20 793.	19 742.	38.58	9 210	8 745−	17
590	23 267.	23 879.	17 613.	25.59	10 577	7 801	11
600	23 804.	25 285.	15 020.	19.04	11 200	6 653	8
610	24 303.	24 366.	12 224.	7.29	10 793	5 414	3
620	24 763.	21 158.	9 434.7	4.95	9 372	4 179	2
630	25 185.	16 179.	6 674.2	—	7 166	2 956	—
640	25 571.	11 453.	4 474.9		5 073	1 982	
650	25 918.	7 347.7	2 773.2		3 254+	1 228	
660	26 230.	4 325.3	1 600.0		1 916	709	
670	26 508.	2 316.8	848.24		1 026	376	
680	26 750.	1 251.9	454.76		554+	201	
690	26 960.	612.00	221.07		271	98	
700	27 139.	309.38	111.27		137	49	
710	27 285.	158.26	57.30		70	25	
720	27 404.	79.47	27.40		35	12	
730	27 493.	38.49	13.75		17	6	
740	27 557.	19.29	8.27		9	4	
750	27 594.	8.28	2.76		4	1	
760	27 607.	5.52	2.76		2	1	
Σ	—	229 960.27	225 764.81	135 062.27	101 858	100 000	59 824

Trichromatic coefficients: x = .38924; y = .38214; z = .22862−.

*† See notes for 2800°K.

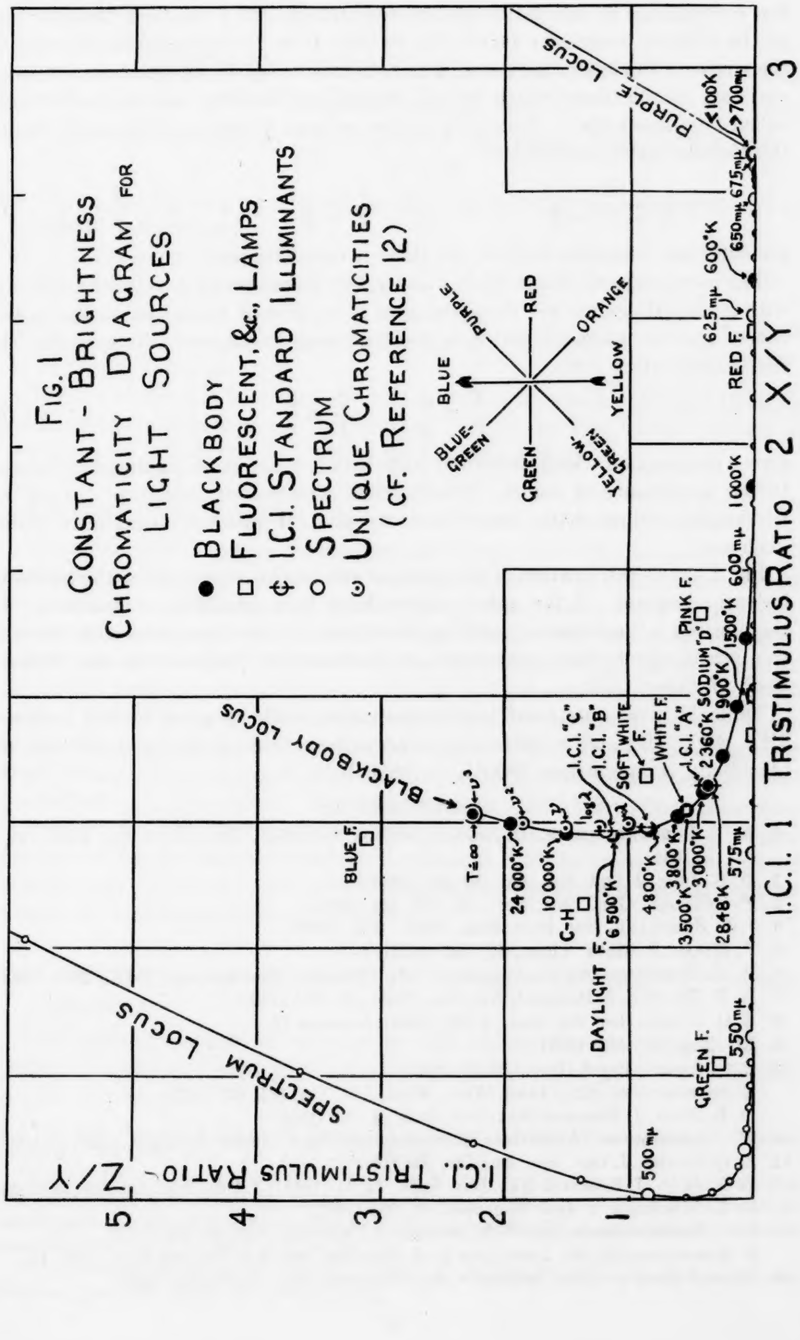

Fig. 1 Constant - Brightness Chromaticity Diagram for Light Sources

For convenience in calculation and representation (*10*) $\bar{y}$ has been chosen equal to the relative luminosity factor K_λ, so that $Y \equiv I$, the luminous intensity of the source. For many purposes, it is preferable to give the luminous intensity and two specifications which do not depend on intensity and are collectively called "chromaticity." Following earlier writers, Young and Maxwell, two of the "trichromatic coefficients"

$$x = \frac{X}{X + Y + Z} \qquad y = \frac{Y}{X + Y + Z} \qquad z = \frac{Z}{X + Y + Z} \tag{7}$$

are sufficient, since the sum of the three is equal to unity.

The most frequent choice (*2*) is x and y; but Uyterhoeven (*11*) gives a diagram with z plotted against y. Since the sum $X + Y + Z$ has no particular significance, and an intensity match is the first step in color-matching lamps, the tristimulus ratios (*12*)

$$\frac{X}{Y} \equiv \frac{x}{y} \qquad \frac{Z}{Y} \equiv \frac{z}{y} \tag{8}$$

give a diagram on which directions and distances are more significantly related to the appearance of colors. Other, more complicated, functions (*13*) of the tristimulus values have been used to give "Uniform-Chromaticity-Scale" diagrams.

Fig. 1 shows the location of the spectral and blackbody colors on the tristimulus-ratio diagram. A few other sources have been added for comparison. In the plotting a "scale factor" of 3 has been used (*12*) to correspond with the relative sensitivity to the components of chromaticity indicated by the *Munsell Book of Color* (*14*).

Table II gives computed tristimulus values, both as given by the products $\bar{x}W_\lambda$, $\bar{y}W_\lambda$, $\bar{z}W_\lambda$, all $\times\ 10^6/c_1$ and as normalized to make $\Sigma\bar{y}W_\lambda \equiv 100\ 000$, for blackbody temperatures 2800°K to 3800°K.

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DENISON SCIENTIFIC ASSOCIATION

Organized April 16, 1887

REPORT OF THE PERMANENT SECRETARY FOR THE YEAR 1942–1943

During the college year 1942–43 the Denison Scientific Association was served by the following officers:

W. A. Everhart, *President*
R. H. Mahard, *Vice-President*
C. S. Ades, *Recording Secretary and Treasurer*
W. C. Ebaugh, *Permanent Secretary and Editor*
L. E. Smith, *Librarian*

It was a pleasure to have the splendid facilities of the new Life Science Building[1] available for meetings of our Association. Unless specified to the contrary all sessions were held in it. A record of the meetings follows.

October 13, 1942

SHOCKED INTO HEALTH. Lynde D. Steckle (Retiring President).

The relationships among psychology, psychiatry and other sciences, and the modern tendency to break down the walls between sciences, were presented as an introduction to a discussion of "shock therapy" for various types of psychoses, dementia praecox and other forms of mental illness. The use of insulin (1927) followed by glucose has proved effective in more than 60% of the cases treated at certain large hospitals, whereas metrazol was effective in only 36% of the cases. If insulin is used within 6 to 12 months of the onset of the disease, prognosis is good; if from one to two years, doubtful; if more than two years, negative. High voltage, low amperage electrical treatment applied to the temple has a good effect upon the patient. Shock by "freezing" until the bodily temperature is reduced to 74°F. produced favorable results with some patients. Surgical operations, like severing the pre-frontal convolution of the brain, were successful only in part. A hopeful conclusion is thus reached: insanity is curable if proper treatment is administered early enough.

October 27, 1942

THE MEANING OF SCIENCE IN HUMAN AFFAIRS. C. Judson Herrick.[2]

This meeting was held in conjunction with one of officers and friends of the Denison University Research Foundation, and Dr. Herrick's paper was published in this *Journal*.[3]

[1] The Life Science Building at Denison University. Arthur Ward Lindsey. *Denison University Bulletin, Jour. Sci. Labs. 36*, 156–159 (1941).

[2] Dr. C. Judson Herrick, a charter member of the Denison Scientific Association, a younger brother of Dr. Clarence Luther Herrick, who founded the *Journal of the Scientific Laboratories* in 1885 and the Denison Scientific Association in 1887, is now professor emeritus (neurology) of the University of Chicago.

[3] The Meaning of Science in Human Affairs. C. Judson Herrick. *Denison University Bulletin, Jour. Sci. Labs. 37*, 140–152 (1942).

"Science itself is human. It is humanity searching—searching out not only the secrets of the world about us, but also the intrinsic values of life. The prime responsibility of science today is to appraise the values for which we work and fight. This science can do, but only if it recognizes these values as its legitimate concern and chief objective."

November 10, 1942

UNSOCIAL MAN. ARTHUR WARD LINDSEY.

The problems of human conduct and human relations are treated by fields other than biology, yet there are biological foundations for anything related to living beings. One of the grave difficulties in regulating our own relations is essentially biological. Like all other animals man's impelling motives to action are essentially the desires for food and reproduction. Due to the long periods of infancy or adolescence in man the coming of children overlap in time, and thus arises the family. Association in a colony or group then follows, but the individual does not lose his identity as an individual, as does a member of a colony of social insects. Human society is a cooperative association of solitary animals: a colony of bees, which are strictly social animals, is something essentially different. The function of the individual in a group of social animals is simply to perpetuate the group. The solitary animal functions only to perpetuate the individual, and not the family or colony. Thus man may adopt many restrictions of individual conduct as a matter of ethical principle or law, and may hope to find means through which individuals may be persuaded to do right because they want to, but his nature as a solitary animal prevents a complete subordination of the individual to the group. The solitary animal must be whipped into cooperative effort by his individual needs: he will not react instinctively to the needs of a group. Efforts to bring about complete subordination of the individual man to his group, be it nation or state, are never completely successful: man remains a solitary animal.

November 24, 1942

FREQUENCY MODULATION. LEON E. SMITH.

Definitions and illustrations of the terms amplitude, frequency and phase, as applied to radio waves in particular, were followed by the explanation that ordinary radios today are controlled by amplitude modification and that the newer type will probably have frequency modulation instead. A mathematical treatment of the problem was followed by descriptions of circuits, radio tubes and other radio devices. Armstrong's frequency modulation (FM), dating from about 1935, is really a phase phenomenon introducing a balanced modulation technique. With the newer type of radio, noise, distortion, fading, interference of unwanted stations and other disagreeable factors are eliminated to a great extent, but the set-up is rather complicated, and the distance of transmission is limited to about 30 miles. No single device has been invented so far that will overcome all undesirable features of radio communication.

December 8, 1942

MODERN CHEMICAL WARFARE. W. C. Ebaugh.

The use of fire, evil-smelling and noxious gases, poisons and other means similar in nature to combat an enemy dates from a very early age; it was not until 1915, however, that modern chemical warfare began. Something of the methods and materiel of this branch of modern warfare, and the defensive means recommended for protecting both combatants and civilians, were presented. The detection of war gases by both odor and chemical means was demonstrated. To the claim that gases have not been used in Europe so far during World War II must be added the statement that this is no guarantee that they will not be used in days to come. Civilian Defense Units are therefore trained to meet the emergency should it arise. Directions for such defense were outlined.

January 12, 1943

THE OPERATIONAL VIEWPOINT IN SCIENTIFIC METHOD. J. H. Rush.

Science is essentially operational, being concerned with correlation of sensory experience; but even modern science has been confused by vestiges of scholastic metaphysics. In the 16th century Galileo upset the geocentric theory of the universe held by scholastics and churchmen of that day. A decade ago it was proclaimed by certain leaders (?) of science in Europe that only that science is right which advances the State, and it must be strictly Aryan (Germanic). Scholastics cast questions in terms of God's motives, thus trying to get outside the universe and then look in. Galileo and other scientists started where they were, and pushed their investigations outward. Copernicus asserted that planetary orbits were circles, as that is the perfect form, and Keppler was almost as bad in clinging to unproved classical notions. Newton, freer from preconceived notions than his contemporaries, nevertheless assumed a frame of reference for motions of heavenly bodies; absolute space and absolute time were assumed without experimental proof. Even today the idea of a "law of nature" is misunderstood by most people, who confuse the idea with that of a law of God or man—usually with a penalty connected with it. Einstein, on the contrary, says that no hypotheses should be made at first: one should take phenomena as one finds them and then find what are the true facts. His experiments show that there is no such thing as absolute space and absolute motion, but everything is relative. He claims that every observation involves two factors: the phenomenon itself and the observer himself; also, that knowledge is gained only by observation of nature, and not by reasoning and philosophizing. John Dewey insists that the connotation and denotation of words are factors in getting knowledge. The modern idea of a "penumbra of uncertainty" with its corollary of greater accuracy due to more refined measuring and observing methods has brought forth discoveries due to the recognition of trivial errors, such as the discovery of the planet Mercury. In the light of operational analysis many old questions disappear, such as absolute space, absolute time and absolute motion.

Motives also disappear: there is no answer to the question "Why?" The principle of uncertainty overthrows the ideas of absolute consequence of cause and effect, yet statistical methods even here bring out new truths. Philosophically the absolute mechanistic ideal is not one hundred per cent sure, and there may be such a thing as "free will" due to variations in the operations of brain and other cells. Politically here in America we have a democracy using operational methods rather than a fixed system, for it is willing to change its methods with altered conditions. The application of scientific method to social processes hinges upon the question of free will in human behavior.

February 2, 1943[4]

SYNTHETICS AND THEIR MANUFACTURE. V. C. PETERSON (The Du Pont De Nemours Company).

A well illustrated account of the origin, development, manufacture, and uses of plastics. Actual specimens of dozens of present day articles made from this relatively new type of material were on display.

February 9, 1943

PROBLEMS ARISING FROM THE MEANDERING OF THE MISSISSIPPI RIVER. RICHARD H. MAHARD.

The tendency of rivers to meander is a phenomenon known to all yet completely understood by no one. This lack of information concerning meandering makes more difficult man's task of solving problems arising from this particular habit. A meander is due primarily to a river's following the line of least resistance. In the case of the Mississippi River a straight channel from Cairo, Illinois to the mouth of the river would be about 60% as long as the real river itself. Problems arising from the meandering habit of the river included boundary changes between states, with taxation, the control of slavery (as between Illinois and Missouri a century ago); navigation; flood control; agricultural use of bottom lands, etc. Engineers believed that by a system of walls and revettments that the course of the river could be shortened appreciably without causing damage by increasing the gradient greatly. By this process of "persuading the river" rather than by "forcing" it to take radically new channels, cutting off meanders of the Mississippi has resulted in a substantial lowering of the flood crest, and as a consequence much damage has been prevented. At the same time conditions for the navigation of the river have been improved.

February 23, 1943

UNSCIENTIFIC MARRIAGE LAWS. F. G. DETWEILER.

Marriage is a contract involving rights of both husband and wife. Our own marriage laws stemmed from the old Common Law of England as well as from ancient practices. But nowadays very different life conditions obtain, especially as to the mobility of people and their tendency to remove hastily from one state

[4] This meeting was held in conjunction with one of the Denison Chemical Society, a student organization that has had an uninterrupted life since October 15, 1909.

to another, and this factor introduces confusion into the marital status of persons —especially in the case of divorce. In Ohio common law marriages are legal, but ordinarily difficult to prove. How about property rights? and bigamy? About 500 A.D. Teutons considered marriage a contract between families. Later the Church exercised authority and insisted that marriages without its sanction were null and void. In England a dual arrangement grew up whereby either a civil or a church marriage was valid. In Ohio today the minimum age is 16 for a girl and 18 for a boy, with consent of the parents required. The "consent" is often a farce, however. In some states 12 and 14 years are allowable. Undoubtedly much falsification is practiced in these matters. As remedies: a waiting period between time of getting the license and the actual wedding; a requirement for securing a medical examination for venereal disease before marriage; a higher fee for license; denial of right to marriage if a contracting party is a victim of drink, drugs or known vices, an imbecile, epileptic or insane; marriage ceremony to be conducted without fee for the officiating justice of the peace, priest, clergyman, etc. Marriage bureaus competently administered can render good service, but they do not reach the classes of society where they are needed most. In divorce cases the time of residence required varies from 15 days in Mexico and 60 days in Nevada to much longer periods in other places. About 85% of the divorces are not contested. At times of high prices there are high marriage, birth and divorce rates. Whereas there is one divorce for 5.5 marriages throughout the country, in our own (Licking) county there is a divorce for each three marriages. The tendency in the United States of America has been to widen the range of acceptable causes for divorce, even incompatibility being allowed. The time of separation in different states varies from a few weeks to as much as 10 years. If one secures a divorce in a given state and goes to another state to be married is the new marriage legal—or does the party concerned become a bigamist? The need for far-reaching revision of marriage and divorce laws on a national instead of a state-wide basis is apparent.

March 9, 1943

CONSUMERS IN WARTIME. LELAND J. GORDON.

Consuming involves choosing, buying, and using of goods and services. The function of a peace-time economy is to produce the maximum volume of desirable goods and services for the people, but in time of war a maximum volume of war material is called for, and a minimum supply of civilian goods and services. One must expect diminishing supplies for the people, inflation, lowered living standards, and altered customs. As counter measures the consumer must make new choices, exercise greater care in buying, and be more economical in using whatever is available to him. In the re-education process necessary to meet the new conditions a study of books and other publications, governmental and civil, on nutrition, clothing, housing, public services, etc. becomes a necessity for the consumer who wants to do his share, yet get the most for his money. A presentation of current price tendencies, tax program, and budget requirements showed that the professional purchasing agent must be emulated. Whereas

normally women do 80 to 90% of the buying, today they must have the active co-operation of husband and children, and all their planning must be based upon ascertained facts such as are supplied by consumer-testing-agencies, government agencies, Council on Foods, Better Business Bureaus, American Dental Association and similar groups. One must go into the markets, buy infrequently, in large lots, in off-season, shop around, investigate the grades of goods more closely, take advantage of cash prices, and be not misled by advertising claims. Guarding against waste, care of equipment on hand (illustrated best by automobiles and tires), care of clothing, and a reexamination of one's insurance program—all are important factors in making the consumer's dollar during wartime do its full duty.

March 23, 1943

THE ENGINEER LOOKS AT THE ARTS COLLEGE. A. W. Davidson (Owens-Corning Fiberglas Corporation).

An engineer is an applied scientist trained in the fundamental subjects physics, mathematics, chemistry, biology, geology and sociology, and in the applied sciences mechanics, thermodynamics and hydraulics. In guiding an engineering school one must bear in mind government licensing requirements, demands of professional engineering societies and accrediting agencies of various kinds. So much is required in the way of tool courses like analytical chemistry, alternating current machines, machine design and many others, there is no room left for so-called cultural courses. The result is often a transition from the class of thinking student who enters college to the regimented memorizer, loaded with facts, but not able to solve problems and do new work, ready to graduate. Surveys of alumni of such schools have shown that after they had been out for 10 to 20 years 7% were eminently successful, 53% held good jobs, and 40% had done nothing to boast about. How can these conditions be improved? The engineering educational subjects themselves require two years: these include the tool subjects English composition (report writing and business forms), applied economics and applied sociology. It is believed that fundamental chemistry, mathematics and physics can be taught better by arts than by engineering schools because they are treated as general principles of wide application rather than as narrow tool subjects to be used in a limited field. Industry recognizes this, and pays more for a man with the broad arts foundation and the limited technical education of later years. For this type of work the 3-2 year plan is quite satisfactory: results with the 6-year plan have not been so gratifying. In the long run, however, the important factor is how the subjects are taught rather than their content: the student must be taught how to think and then translate into engineering practice the principles learned in his various courses. Is the arts college doing this job as well as it ought to be done?

April 13, 1943

THE FAILURE OF THE TACOMA NARROWS BRIDGE. C. S. Ades.

A catastrophic event befalling the engineering world and startling the general public was the failure of this relatively long span suspension bridge. To explain

the failure a brief resume of the history of suspension bridges was given, and then followed a presentation of the case in hand, using models of the action and design of such bridges. Colored moving pictures were used to depict events immediately preceding and following the actual failure of the bridge. Lessons learned and precautions to be used in preventing similar accidents hereafter concluded the discussion.

April 27, 1943

PROBLEMS INVOLVED IN PREVENTING THE ABSCISSION OF LEAVES, FLOWERS, AND FRUIT, AND IN THE DEVELOPMENT OF PARTHENOCARPIC FRUIT. R. M. MEYERS.

Why do flowers, fruits and leaves fall off? Often leaves fall prematurely in summer, flowers may fall before the fruit can develop, and fruit itself falls before it ripens. To explain these processes illustrations of flower and leaf anatomy, the effect of growth substances in preventing the abscission of debladed petioles, the effects of growth substances on the growth of debladed petioles, the normal development of fruit when the flower is pollinated in the usual way, the development of parthenocarpic fruit (fruit developed without pollination, and usually seedless—like navel oranges), and the direct effects of growth substances on absciss layer of potato and tomato flowers—were shown. The blade of the leaf seems to generate a growth substance (hormone-like) which diffuses down to the petiole, and there prevents the abscission: stimulation of the absciss layer seems to prevent "aging" and consequent breaking off. Practical applications of the theory involve the use of certain growth-producing substances to prevent preharvest dropping of fruit, the abscission of tomato blossoms during cloudy weather, and to keep the flowers on potatoes, thereby assisting in plant breeding experiments.

May 11, 1943

A closed dinner and business meeting at the Granville Inn.

Officers for the college year 1943–1944 were elected as follows:

R. H. Mahard, *President*
C. S. Ades, *Vice-President*
J. H. Rush, *Recording Secretary and Treasurer*
W. C. Ebaugh, *Permanent Secretary and Editor*
L. E. Smith, *Librarian*

Three numbers of the JOURNAL OF THE SCIENTIFIC LABORATORIES OF DENISON UNIVERSITY were issued during the college year 1942–1943, *viz.*:

Vol. 37, Articles 3–7, pp. 67–132, August, 1942

Megaliocrinus, A new Camerate Crinoid Genus from the Morrow Series of Northeastern Oklahoma; Raymond C. Moore and Lowell R. Laudon. 10 pp., 5 figs.

Metacatillocrinus, A new Inadunate Crinoid Genus from Pennsylvanian Rocks of Oklahoma; Raymond C. Moore and Harrell L. Strimple; 8 pp., 6 figs.

Blastoids from Middle Pennsylvanian Rocks of Oklahoma; Raymond C. Moore and Harrell L. Strimple; 7 pp., 1 fig.

A New Species of Synbathocrinus from Mississippian Rocks of Texas, with Description of Ontogeny; Raymond C. Moore and John D. Ewers. 15 pp., 28 figs.

Mercury Vapor Lamps; W. E. Forsythe, E. Q. Adams and B. T. Barnes. 26 pp., 20 figs.

Vol. 37, Articles 8–9, pp. 133–163, December, 1942
- Geography in a World at War; C. Langdon White. 7 pp.
- The Meaning of Science in Human Affairs; C. Judson Herrick. 13 pp.
- The Denison University Research Foundation. 1 p.
- Report of the Permanent Secretary of the DENISON SCIENTIFIC ASSOCIATION. 7 pp.

Vol. 38, Articles 1–2, pp. 1–39, April, 1943
- Establishing and Maintaining a Color Temperature Scale. W. E. Forsythe and E. Q. Adams. 31 pp., 9 figs.
- The Vegetation of Idaho. R. Maurice Myers. 8 pp., 1 fig.

War conditions have had their natural effects upon our Journal. Both the amount of material received for publication and the quantity of scientific literature sent to us by our exchanges have diminished greatly. Distribution has been limited practically to the Western Hemisphere and the British Empire. Numbers of our Journal are being held for shipment in the postwar period: this applies not only to current issues, but also to back numbers that will inevitably be needed to make good the destruction and loss of books due to the ravages of war.

War has also had its effect upon the personnel of our Association. With some of our members called into the armed forces and others assigned to duties in scientific work supporting the war effort, there was a falling-off in membership; with the coming of training units from the Army and Navy to the campus of Denison University, however, a notable increase in the number of teachers of mathematics and physics has occurred. Interest in the Association has not lagged.

Orders for back number of the Journal—especially for complete sets destined for libraries—have been surprisingly numerous. Persons having unwanted back numbers will be conferring a favor upon the Association, and indirectly upon possible purchasers in days to come, by sending them to the Permanent Secretary for addition to our reserve stocks.

In the era of peace following World War II at some indefinite date, we can look forward confidently to continued scientific investigation, publication, and progress. Much that can not be printed now will be available then: the recognition of the part science has played in the all-out war effort on the production front as well as on the fighting front will establish science more firmly than ever as a dominant factor in human affairs.

Respectfully submitted,

W. C. Ebaugh, *Permanent Secretary and Editor*

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